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Measurement of Gravity at the Viking Gas Terminal, Theddlethorpe St Helen, Lincolnshire

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ENGINEERING GEOLOGY PROGRAMME

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Measurement of Gravity at the Viking Gas Terminal, Theddlethorpe St Helen, Lincolnshire

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Summary

This report describes the results of three gravity measurements made by the British Geological Survey (BGS) for ConocoPhillips Ltd., Viking Gas Terminal, Theddlethorpe St. Helen, Mablethorpe, Lincolnshire. The site of the measurement was on the floor of the Metering Calibration Laboratory, adjacent to the deadweight testing machines. The measurement was made by means of a series of links between the site and a British Precise Gravity Network (BPGN93) base station at St Sebastian's Church, Great Gonerby, using a Lacoste and Romberg type G gravity meter.

The values of gravity 'g' established for the measurement points at the Viking Gas Terminal are shown below:

9.813 529 8 ± 0.000 000 3 ms^{-2}

1 Introduction

At the request of Phil Devereux of ConocoPhillips Ltd., the British Geological Survey (BGS) undertook to provide three measurements of the acceleration due to gravity ('g') at the Viking Gas Terminal, Theddlethorpe St Helen, Mablethorpe, Lincolnshire.

In order to establish a value of 'g' simply and swiftly it is necessary to measure a gravity difference between the specified site and a site where an absolute value of 'g' has been previously determined. Such absolute values are available on the British Precise Gravity Net 1993 (Charles and Hipkin 1995) which is linked to a number of points at which gravity has been measured using a high accuracy FG5 absolute gravity meter.

Gravity differences may be determined using portable gravity meters, which are effectively high-sensitivity spring balances, contained in a temperature and pressure controlled box. Gravity meters are subject to 'drift' as a result of the main measuring spring deforming over time. In order to compensate for this effect, data are collected within closed loops starting and finishing at a point of known gravity. Having made a correction for earth tides, which result from the gravitational effect of the sun and moon and which cause a daily cyclical variation in 'g', any differences in reading are attributed to drift and distributed linearly with time around the loop. Normally a series of three base readings and two station readings are made, a so-called A-B-A-B-A link. Additional A-B-A loops may be performed if the initial series of readings does not produce a result of sufficient quality, for example due to excessive instrument drift or noisy ground conditions.

2 The Survey

The instrument used for these measurements was Lacoste and Romberg series G gravity meter #G456, which has a long record of proven reliability and small, regular drift. The calibration was checked in 1996 (Chacksfield, 1996) and 1999 (Chacksfield, 1999) and found to conform to the original maker's calibration factor of 0.010540 mGal per scale division (1mGal = 10^{-5} m s^{-2}). Further calibrations have been carried out, the most recent in November 2013 confirming continued reliable performance of the meter, but the calibration factor was revised to 0.010543 (Morgan Personal Communication).

The BPGN93 Great Gonerby site was used, located at the St Sebastian's Church, Great Gonerby, Lincolnshire at National Grid Reference 489800 338100, 75 km to the southwest of the Viking Gas Terminal site. The site is illustrated in Figures 1 and 2. The BPGN93 site was located on the ground, on the outer step of porch on the south side of the building and access was simple. Reading conditions were stable on the first loop; the readings are consistent, with a maximum variation of 0.01 mGal.

The point for which the value was determined is in the metering calibration laboratory, as shown in Figure 3. The spot was marked with marker pen, which should be replaced by a permanent feature shortly. A small amount of vibration was observed, which may have been caused by a mobile crane operating outside the building. This did not seriously affect the readings, but may have contributed to the error. Each measurement was repeated at least twice, with the meter clamped and moved off-level between each one. The readings are consistent, with a maximum variation of 0.02 mGal. A series of loops from BPGN93 Great Gonerby were measured, sufficient to confirm the reliability of the readings within a reasonable amount of drift. The survey was conducted over a period of some 10.5 hours during the day of 17th June 2014.

The instrument readings are shown in Table 1, which also indicates the earth tide correction and the resulting gravity values in meter units. Figure 4 shows the plot of instrument readings against time. A linear drift rate was assumed between successive occupations of each station. The

differences between the measured value at the Laboratory and the value interpolated from the two base station values were determined graphically and the mean was calculated.

Table 1: Gravity measurements for link between British Precise Gravity Network 1993 (BPGN93) Great Gonerby and the Viking Gas Terminal, Theddlethorpe. Meter units are approximately 0.01 mGal (10^{-7} ms^{-2}).

Site	Time	Observed Value (meter units)	Tide Correction (meter units)	Tide Corrected Value (meter units)
Great Gonerby	07:33	481092	-7	481085
Great Gonerby	07:35	481092	-7	481085
Great Gonerby	07:37	481092	-7	481085
Great Gonerby	07:39	481092	-7	481085
Theddlethorpe	10:32	485234	-5	485229
Theddlethorpe	10:37	485234	-5	485229
Theddlethorpe	10:39	485234	-5	485229
Theddlethorpe	10:44	485235	-5	485230
Great Gonerby	12:55	481082	0	481082
Great Gonerby	12:58	481082	0	481082
Great Gonerby	12:59	481082	0	481082
Theddlethorpe	15:20	485225	4	485229
Theddlethorpe	15:26	485225	4	485229
Theddlethorpe	15:31	485224	4	485228
Great Gonerby	17:59	481077	2	481079
Great Gonerby	18:03	481079	2	481081
Great Gonerby	18:05	481078	2	481080

Table 2: Gravity differences between British Precise Gravity Network 1993 (BPGN93) Great Gonerby and the Viking Gas Terminal, Theddlethorpe.

Site	Time	Mean reading	Mean reading – Great Gonerby (drift corrected)
Great Gonerby	07:36	481085.0	
Theddlethorpe	10:38	485229.3	485229.3 - 481083.2 = 4146.1
Great Gonerby	12:57	481082.0	
Theddlethorpe	15:26	485228.7	485228.7 - 481081.0 = 4147.7
Great Gonerby	18:02	481080.0	

Results

2.1 METERING CALIBRATION LABORATORY FLOOR

The mean difference between Great Gonerby BPGN93 Base Station and the Metering Calibration Laboratory floor was:

+4147± 3 dial units

This was converted to gravity by multiplying by the instrument calibration factor 0.010543:

+4147 x 0.010543 = +43.72 ± 0.03 mGal.

The absolute value at Great Gonerby BPGN93 Base Station is given as:

981 309.2562 ± 0.0043 mGal.

The value of 'g' on the floor of the Metering Calibration Laboratory is obtained by adding the difference to the absolute value at Great Gonerby BPGN93 Base Station

(981 309.2562 ± 0.0043) mGal + (43.72 ± 0.03) mGal = 981 352.98 ± 0.03 mGal

The value of 'g' in SI units (i.e. ms^{-2}) is obtained by multiplying the value in mGal by 10^{-5}.

(981 352.98 ± 0.03) x 10^{-5} = 9.813 529 8 ± 0.000 000 3 ms^{-2}

3 Use of the Value

The measurements were made on the floor of the Metering Calibration Laboratory. The value of gravity determined therefore refers to those points. The gravity values at other points, small distances from the measured points, will vary due to a number of factors:

- The height of the point relative to the measured point (the free air effect)
- The regional variation of the gravity field due to density variations in the earth's crust (the Bouguer gravity anomaly)
- The North-South position of the point relative to the measured point (the latitude effect)
- Local gravity variations due to severe local topography (natural or man-made – e.g. cuttings/embankments) (the terrain effect)
- Local density variations in the vicinity of the laboratory e.g. cellars, pits or large, high-density objects.

3.1 HEIGHT CORRECTION

The value of gravity above a measured point will be reduced due to the free-air effect. The correction which must be applied to determine the value of gravity above the measured point is:

-3.086×10^{-6} ms^{-2} per metre.

A 1 metre high bench (of negligible density) would give a value 0.31 mGal lower than a point directly below it.

3.2 BOUGUER GRAVITY ANOMALY

Bouguer gravity anomalies show the gravity variation which is due to variations in subsurface densities (i.e. the variations which are of interest to earth scientists etc.) These anomalies are calculated by removing the effects of Elevation, Latitude, and local terrain from the observed gravity values.

The data for an area several kilometres around the Viking Gas Terminal have been processed in this way and are shown as a contoured plot in Figure 5. This shows a negative Bouguer gravity anomaly of -11.9 mGal, and indicates that there is a consistent, relatively gentle anomaly gradient in the vicinity of the site, with the direction of maximum gradient being north to south (increasing to the south). The lateral variation of the Bouguer gravity anomaly field in the vicinity of the site is estimated to be of the order of:

0.10 mGal (1×10^{-6} m s^{-2}) per km in an southerly direction

A point some **10m** to the **south** of the measured point in the laboratory would result in an **increase** of the gravity field of approximately **0.001 mGal**, due to the Bouguer gravity anomaly i.e. less than the observational error.

3.3 LATITUDE CORRECTION

The value of gravity at some horizontal distance from the measured point increases by approximately **1×10^{-8} ms^{-2}** per metre in a northerly direction (due to the Earth's radius decreasing to the north). The latitude correction is therefore less than observational error for distances of less than 10 metres in a northerly direction. The east-west latitude correction is zero.

3.4 TERRAIN EFFECT

No severe topography, cuttings etc. were observed in the immediate vicinity of the site.

3.5 LOCAL ON-SITE ANOMALIES

No cellars, pits or large, massive, high density objects are known in the vicinity of the laboratory, however, without detailed knowledge of the site the possibility of local anomalies cannot be completely dismissed.

3.6 CONCLUSIONS

The gravity values refer to measured points at their positions relative to ground level and relative to Ordnance Datum. The Free-Air correction should be applied for work carried out at any other height. The work should be carried out on benches which have a low total mass. If the work platform is constructed of high density materials, for example solid concrete or massive iron/steel, consideration must be given to the density of the platform.

The gravity values calculated for the measured points should only be used for high precision work within a small distance (10m) of the point. If used other than at the measured point consideration should be given to local variations, e.g. high density objects, basements etc.

Edinburgh University – Gravity Station Information
Reference# 205

County	ENGLAND	
Region/County	LINCOLNSHIRE	
Nearest Town	Grantham	
Name	**St. Sebastian's Church, Great Gonerby**	
Latitude	+52.93200°	Grid Reference
Longitude	-0.66400°	489800 338100

Station Description

Leave the Aa1 at the services 1 mile north of Grantham. Take the B1174 into Great Gonerby. The church is at the south end of the village on the east side of the road, next to the primary school. The site is on the outer step of the porch which is on the south side of the building.

For access contact: Rev. Peter Hopkins, The Rectory, Long Street. Tel. 01476 565737

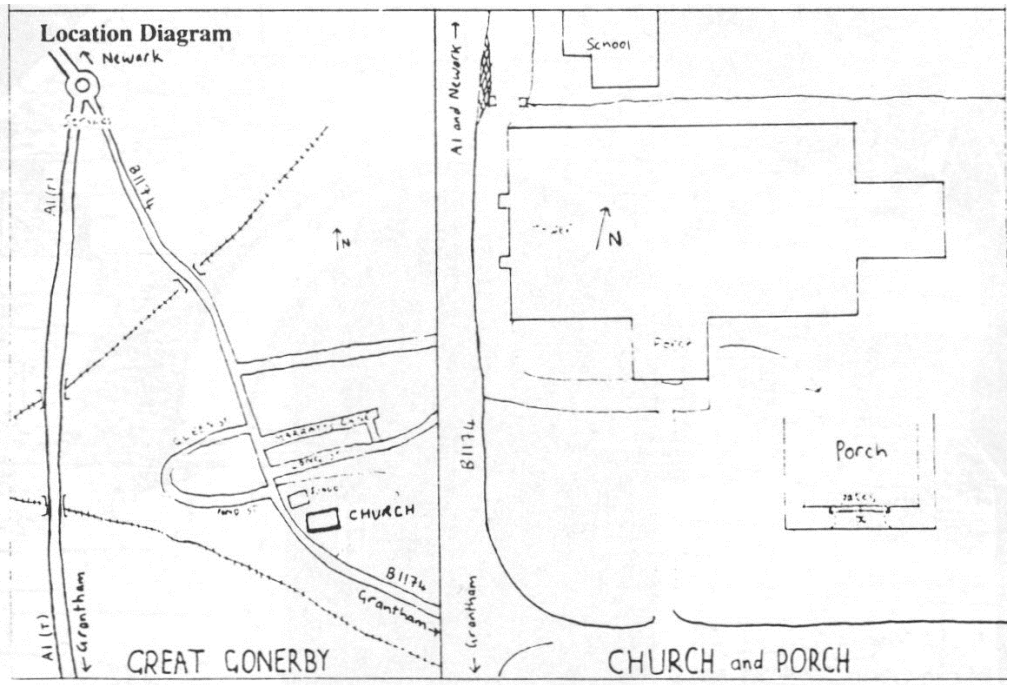

Figure 1: Details of Great Gonerby British Precise Gravity Network (BPGN) at St Sebastian's Church, Great Gonerby.

Figure 2: Photograph showing the position of gravity measurement at St Sebastian's Church, Great Gonerby BPGN93 Gravity station.

Figure 3: Photographs showing the position of gravity measurement on the floor of the Metering Calibration Laboratory, Viking Gas Terminal. The measurement point is under the meter: at the midpoint between the two deadweight tester benches (to the left and right), and 1.70m from the back wall.

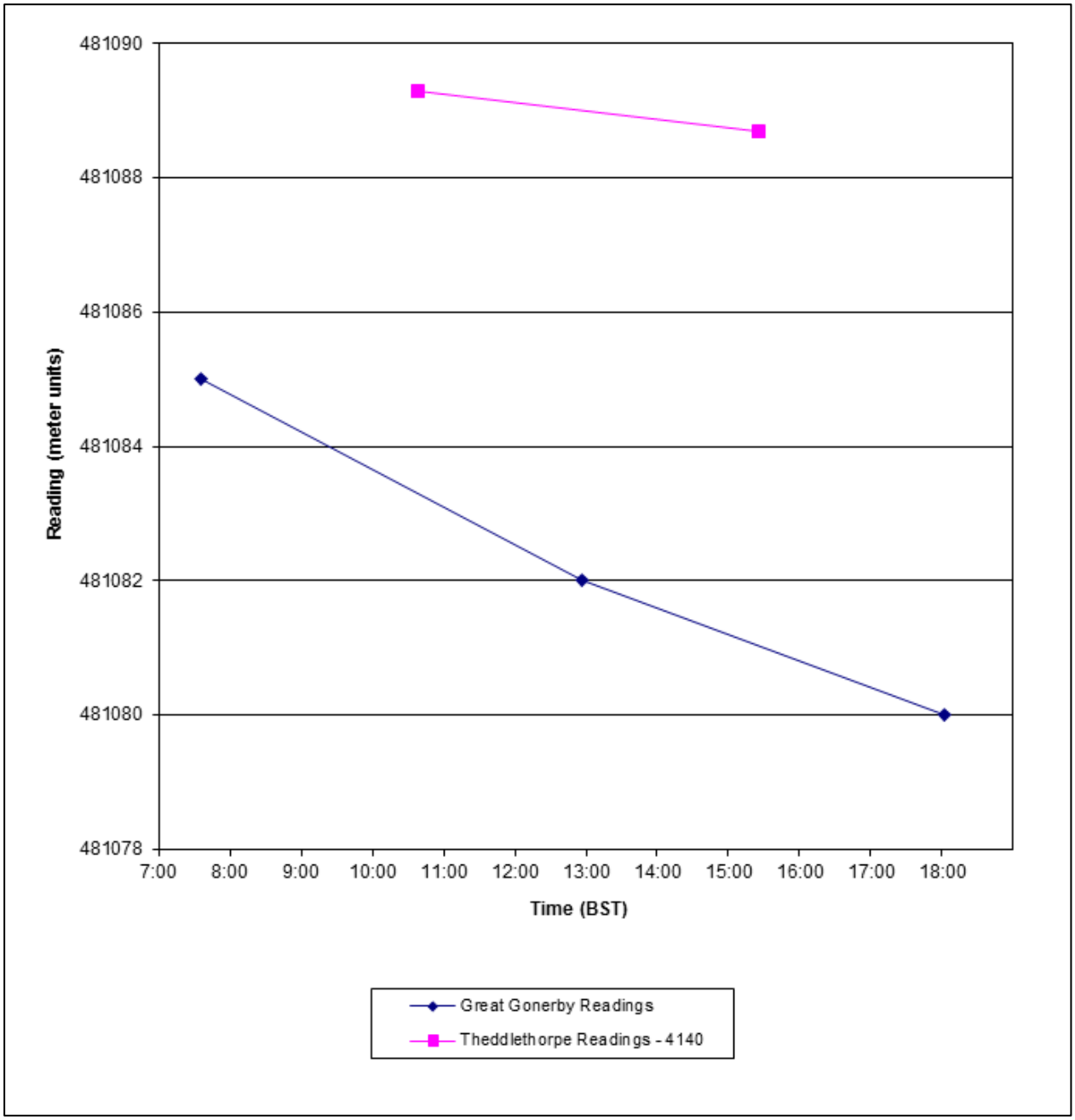

Figure 4: Plot of instrument readings against time

Figure 5: Regional Bouguer gravity anomaly field for the Viking Gas Terminal, Theddlethorpe St Helen and surrounding area with 0.1mGal contours, in red. Regional gravity stations shown as red points, position of the gravity measurement shown as a green point.

References

British Geological Survey holds most of the references listed below, and copies may be obtained via the library service subject to copyright legislation (contact libuser@bgs.ac.uk for details). The library catalogue is available at: http://geolib.bgs.ac.uk.

CHACKSFILED, B.C 1996. Results of a gravity meter inspection and calibration run using the British Precise Gravity Network (BPNG93) in April 1996. *British Geological Survey, Regional Geophysics Group Project Note* PN/96/02.

CHACKSFIELD, B.C 1999. Current status of the BGS model G gravity meters, April 1999. *British Geological Survey Regional Geophysics Group Project Note* PN/99/06.

CHARLES, L. AND HIPKIN, R. 1995. British Precise Gravity Net 1993. Department of Geology and Geophysics, University of Edinburgh.